FALLEN-TIMBER LOADS ON SOUTHERN MURRAY-DARLING BASIN FLOODPLAINS: HISTORY, DYNAMICS AND THE CURRENT STATE OF BARMAH-MILLEWA

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MAC NALLY, R. & PARKINSON, A., 2005. Fallen-timber loads on southern Murray-Darling Basin floodplains: History, dynamics and the current state of Barmah-Millewa. *Proceedings of the Royal Society of Victoria* 117(1): 97-110. ISSN 0035-9211.

Historical sources of information were examined to develop a picture of the structure of River Red Gum *Eucalyptus camaldulensis* forests of the southern Murray-Darling Basin prior to European settlement. We sought information on the density and distribution of fallen timber (grounded logs and limbs ≥ 10 cm diameter). None of these potential sources yielded much useable information to estimate fallen timber loads prior to European settlement. There is good evidence that the structure and demography of red gum forests has been significantly altered since the 1830s, with the former parklands of large, veteran trees > 500 yr being replaced by ranks of smaller, younger trees. Large trees are more likely to produce larger amounts of fallen timber, so that the landscape-scale changes in demographics coupled with the massive reduction of the area of floodplain forest are likely to have produced a much lower total fallen timber load across the whole Murray-Darling basin. Alterations of flooding and wildfire regimes, and the incessant demands for large amounts of firewood are likely to maintain the paucity of fallen timber compared with the early part of the 19th century. The current status of fallen timber in the Barmah-Millewa forest is also described.

Key words: Australia, *Eucalyptus camaldulensis*, historical wood loads, restoration

PRIOR to European settlement, the inland slopes and plains of southeastern Australia supported a variety of open forest and woodland vegetation communities with a high diversity of fauna. These habitats are now some of the most poorly conserved and degraded plant associations in south-eastern Australia (Walker et al. 1993; Robinson 1994; Whitten and Bennett 1998). Vast areas have been cleared for agricultural development. In south-eastern South Australia, ca 14% of the original cover of woodland and open forest remains (Harris 1986), while in Victoria, less than 7% still exists in some areas (Robinson 1994; Bennett et al. 1998). Remnants have been degraded by mining, timber harvesting, firewood collection, inappropriate fire regimes, grazing by stock and by rabbits, and changes in hydrology. Historical records indicate that the degradation and loss of these environments have also been accompanied by major declines in local and regional faunal diversity (Bennett et al. 1998; ECC 1997).

Habitat restoration is needed to improve the quality of remaining areas of forest and woodland. This requires an understanding of how specific habitat characteristics influence species diversity.

Ecological significance of fallen timber

One component of Australian forest and woodland ecosystems that has received little attention by ecologists is fallen timber. We use the definition of Harmon et al. (1986) for describing fallen timber: grounded limbs and logs with a minimum diameter of 10 cm. Although fallen timber is a prominent structural feature of natural eucalypt communities, it is often seen as a fire hazard. Thus, in the past, much effort has been made to clear timbered areas of fallen timber.

Fallen timber serves a number of important ecological functions. It provides habitat for many groups of animals including small mammals, reptiles, frogs and invertebrates, and serves as a nutrient source for many invertebrates, micro-organisms, fungi and flora (Harmon et al. 1986). It also plays an

important role in nutrient and energy cycling within ecosystems, and influences soil and sediment transport and storage (Harmon et al. 1986). In aquatic systems, fallen timber has the additional effect of influencing stream morphology as well as providing the only solid substrate in many instances.

While a number of studies investigating the ecological significance of fallen timber have been conducted in the northern hemisphere (see review by Harmon et al. 1986), little work has focused on fallen timber in terrestrial Australian environments (although see Brown et al. 1996; Robinson 1997; Williams and Faunt 1997; Laven and Mac Nally 1998).

On the floodplain of River Red Gum forests, fallen timber is likely to be a vital resource for both terrestrial (Mac Nally et al. 2002a; Mac Nally and Horrocks 2002; Boyd et al. 2005) and aquatic (Ballinger et al. 2005) organisms, and also is much affected by firewood collection. The floodplains of the inland rivers of southeastern Australia are dominated by River Red Gum, a timber favoured as a fuel. Our surveys suggest that the current loads may be about 15% of former loads (see Mac Nally et al. 2002b).

Objectives

The current study evaluated documentary information concerning pre-European levels of fallen timber on the Murray-Darling floodplains, with which existing levels can be compared. In the process, this may provide target levels for future restoration of fallen timber in these environments.

Information was compiled from the earliest historical sources available. Potentially useful data on the nature of floodplain environments was produced by five major groups of people during the 19th century: explorers, squatters and selectors, government surveyors, scientists and naturalists, and foresters. Relevant records include documents such as journals, river charts, land files, pastoral plans, parliamentary reports and forestry records. As it was anticipated these early records may yield a paucity of direct data on fallen timber loads, a detailed examination of how changing land-management practices have influenced fallen-timber dynamics was also undertaken. This allows some inferences to be made about how fallen-timber loads may have changed.

Focal area: southern Murray-Darling floodplains

The River Red Gum *Eucalyptus camaldulensis* is the characteristic tree species of the lowland floodplains of the Murray-Darling Basin. Its occurrence along inland watercourses makes it the most widely distributed of all eucalypts. River Red Gum communities range from open woodlands of trees with short boles and large, spreading crowns, to tall forests of trees up to 45 m in areas where the floodplain is prone to more prolonged floods (Wilson 1995). River Red Gums typically occur in pure stands with an understorey of grasses or wetland plants. The shrub layer generally is lacking or sparse. Less frequently inundated areas of floodplains are dominated by Black Box *Eucalyptus largiflorens*. This study focuses primarily on the River Red Gum ecosystems of the southern Murray-Darling Basin (south of the 32° 22' S).

HISTORICAL OVERVIEW

> '... stately yarra trees; and charming vistas through miles of open forest scenery... the whole country traversed this day, was of that description which belongs to the margins of streams, being grassy land under an open forest containing goborro [box] and yarra [River Red Gum] trees.' Thomas Mitchell, Lower Murrumbidgee River, 1836 (Mitchell 1965b)

When Major Thomas Mitchell travelled down the Lachlan, Murrumbidgee and Murray Rivers in 1836, he described floodplain environments untouched by white settlers. These riverine woodlands were inhabited by thousands of Aboriginal people (Allen 1979; Buchan 1979; Webb 1984). The rivers and floodplains provided an abundance of natural resources. The lands were used by Aborigines for at least 40,000 years prior to European settlement (Lance 1985).

Within a few years of the exploration of the lowland rivers of the Murray-Darling system, squatters began to claim the land for pastoral runs. The lush grass growing on the riverine flats following the retreat of flood waters provided abundant feed for stock over the dry summer months. The Land Acts of the mid 1800s opened the land to selectors, and new townships and local industries flourished.

Clearance of trees for agriculture and settlement has significantly reduced the extent of native flood-

plain vegetation. Margules and Partners et al. (1990) estimate that 33% of floodplain vegetation has been cleared along the Murray River and its anabranches, although much of this is likely to be box woodlands on the outer edges of the floodplains. River Red Gum has suffered significantly less loss of cover in comparison to other inland community types (Bennett et al. 1998) due to the flood-prone nature of these areas.

Other changes in land-use and management practices have had a major impact on floodplain ecosystems. The vegetation history of these environments has been previously documented by a number of authors (e.g. Curr 1965; Chesterfield 1986; Bren 1992; Margules and Partners et al. 1990; McGowan 1992; Donovan 1997). Forestry practices and changed burning regimes have caused many changes in the structure of River Red Gum communities (Jacobs 1955; Lyons 1988; Wilson 1995; Donovan 1997).

The degradation that has occurred over the last 150 yr also has contributed to the loss and decline of many species of animals (MDBMC 1987; Bennett et al. 1998). The Blandowski expedition in 1856-57 recorded 32 mammal species, excluding bats, in the vicinity of the Murray-Darling junction (Wakefield 1966). Twenty-two of these species are now locally extinct in the area (MDBMC 1987). Studies investigating the causes of decline in species richness within floodplain environments have mostly focused on the effects of hydrological changes associated with river regulation, particularly on waterbirds (although see Parkinson et al. 2002). On a broader scale, declining numbers of hollow-dependent fauna in most habitat types has been attributed to the loss of large, old, hollow-bearing trees across forest and woodland communities in general. Virtually nothing is known about historical changes in fallen timber availability and possible impacts on floodplain fauna.

Historical Records

By the late 1800s, floodplain environments already had undergone major changes as a result of European impacts. The first explorers, settlers and naturalists provided the earliest descriptions of these areas, often describing environments previously unseen by European colonists (1810-60). Later data collected by government officials (surveyors, scientists and foresters) were examined, although these mostly pertained to environments that had already undergone much alteration (1860-1900).

Historical records were examined for any data (descriptive or quantitative) that provided either a direct indication of fallen timber availability, or that gave information on other variables (e.g. tree densities, fire regimes) that may relate to fallen timber availability.

Explorers and Overlanders

Within a few years of the crossing of the Blue Mountains and up to 1836, Oxley, Hume, Hovell, Mitchell and Sturt had travelled extensively in the region. The first colonists were the overlanders, who used the Murray River as a travelling stock route to drove cattle to Adelaide (Hawdon, Bonney, Sturt and Eyre).

The journals of these explorers and overlanders showed a number of common themes among their descriptions of the floodplain forests (Table 1). Almost all of the explorers commented on the large size of the trees growing along the rivers (extracts 2, 6, 9, 11, 12, 15, 16, 17, 22, 24; Table 1). In many areas, the vegetation had an open, park-like appearance with extensive grassy plains (7, 19, 21, 22, 24, 26, 28), while in other areas, the trees were dense (1, 8, 25, 27, 29, 31). There are also many references to aboriginal burning and its effects on the vegetation (3, 4, 5, 10, 13, 23, 32, 33).

A number of extracts provided information about fallen timber (Sturt's journals). A swampy region in the vicinity of the junction of the Murray and Edward Rivers was 'full of decayed timber' (30). Fire-damaged trees were an important source of fallen timber (32, 33), and considerable volumes of debris were moved into the river channels during floods (34). Sturt mentioned 'the frequent stumbling of the cattle' (8), possibly due to much fallen timber. None of the other explorers mentioned fallen timber as an impediment despite travelling through these areas with bullock trains and drays.

Squatters and Selectors

Squatters moved into the newly explored territories. By 1830, pastoral runs had been taken up along the Murrumbidgee and Lachlan frontages; 1835 saw runs on the Murray River at the present-day site of Albury; by 1838 the country along the Goulburn,

Explorer (year)	Area	Extract
John Oxley (1817)	Lachlan River	1. 'The banks were so thickly covered with large eucalypti, that we did not perceive it until we were within a very few yards of it.' (Oxley 1964:78-79) 2. '…huge unshapen eucalypti, which would not afford a straight plank ten feet long…' (Oxley 1964:83)
Hamilton Hume William Hovell (1824-25)	Ovens River Goulburn River	3. 'All the country from where we started this morning is all burning in every direction and the bush is all on fire … the blacks…' (Hovell 1921:343) 4. '…all the country around us appears to be on fire…' (Hovell 1921:359) 5. 'The country is on fire in all directions. This appears to be the season for burning the old grass to get new.' (Hovell 1921: 361)
Charles Sturt (1828)	Macquarie River	6. 'Upon these low grounds the blue-gum trees were of lofty growth…' (Sturt 1963:11)
	Darling River (near Macquarie River junction)	7. '…on the immediate banks of the river, where its undulations and openness gave it a park-like appearance' (Sturt 1963:23) 8. '…timbered sufficiently to afford a shade … but we were obliged to seek more open ground, in consequence of the frequent stumbling of the cattle.' (Sturt 1963:29) 9. '…the trees that overhung it were of beautiful and gigantic growth.' (Sturt 1963:86) 10. '…the bush had been fired.' (Sturt 1963:91)
Charles Sturt (1829-30)	Murrumb. River Lower Darling River Lower Murray River	11. 'Flooded-gum trees of lofty size…' (Sturt 1963:52) 12. 'Its banks were sloping and grassy, and were overhung by trees of magnificent size.' (Sturt 1963:108) 13. 'It was evident that fires had made extensive ravages in the neighbourhood… (Sturt 1963:88) 14. '…wherever reeds prevailed the flooded or blue gum stretched its long white branches over them.' (Sturt 1963:133)
Thomas Mitchell (1835)	Darling River	15. 'On the river bank, trees peculiar to it, grow to so large a size, that its course may be easily traced at great distances … these gigantic trees…' (Mitchell 1965 vol.1:302) 16. 'We saw enormous trees by the riverside.' (Mitchell 1965 vol.1)
Thomas Mitchell (1836)	Lachlan River	17. 'The 'yarra' grew here, as on the Darling, to a gigantic size, the height sometimes exceeding 100 feet…' (Mitchell 1965 vol.2:54)
	Lower Murrumbidgee River	18. '…all permanent waters are invariably surrounded by the 'yarra'…' (Mitchell 1965 vol.2:55) 19. '…stately yarra trees; and charming vistas through miles of open forest scenery…' (Mitchell 1965 vol.2:75)
	Loddon River (general)	20. '…most of our encampment placed, unavoidably under a large yarra tree, a very unsafe position during high winds, but fortunately no branches fell.' (Mitchell 1965 vol.2:85) 21. '…the whole country traversed this day, was of that description which belongs to the margins of streams, being grassy land under an open forest containing goborro and yarra trees.' (Mitchell 1965 vol.2:104) 22. '…we passed alternately over grassy plains, and through belts of lofty Gum trees…' (Mitchell 1965 vol.2:111) 23. 'Fire, grass, kangaroos, and human inhabitants, seem all dependant on each other for existence in Australia … Fire is necessary to burn the grass and form those open forests…' (Mitchell 1969:412)
Joseph Hawdon Charles Bonney (1838)	Lower Goulburn River	24. 'The lagoons here begin to extend to a greater distance from the river, and are studded with very lofty flooded gum-trees, with good grass between them…' (Kain 1991:30)
Charles Sturt (1838)	Murray River (near Edward River junction)	25. '… under a dark wood of gum trees scathed by fire to their very tops.' (Sturt 1838 cited in Sturt 1899:138) 26. '…scattered trees marked with pleasing verdure the course of the river.' (Sturt 1838 cited in Sturt 1899:139)

Table 1. Extracts from the journals of explorers and overlanders.

Explorer (year)	Area	Extract
Charles Sturt (1838)	Murray River (near Echuca) (near Swan Hill) (general)	27. '...the cattle walk through beautiful green feed, up to their middles in grass. The trees are not so large as those higher up the river ... and the view is shut in by thick forest.' (Sturt 1838 cited in Sturt 1899:141) 28. '...we traversed splendid and open flats of rich light loam. They were so large as almost to deserve the name of plains.' (Sturt 1838 cited in Hibbins 1978:20) 29. '...we found the country on both sides of the river free from reeds, but heavily timbered...' (Sturt 1838 cited in Hibbins 1978:21) 30. '...found the country intersected by deep creeks, full of decayed timber, and marked by bull rushes and reeds...' (Sturt 1899:10) 31. 'The whole country was heavily timbered...' (Sturt 1838 cited in Hibbins 1978:22) 32. 'When timber was again seen it was like the reeds, blackened by native conflagrations. Huge trunks and leafless limbs lay one across another on ground as black as themselves.' (Sturt 1838 cited in Sturt 1899:143) 33. 'The reeds had been burnt by the natives and in burning had set fire to the largest trees and brought them to the ground.' (Sturt 1838) 34. 'But the sudden freshes to which the rivers of this country side are subject, and the immense quantity of timber swept into their beds by each successive flood must ever render them dangerous...' (Sturt 1838 cited in Sturt 1899:145)

Table 1. Extracts from the journals of explorers and overlanders (continued).

Campaspe and Loddon Rivers in the Port Phillip district was occupied (Jeans 1972; Ronald 1960). Squatters in the 'unsettled districts' were granted 14-yr pastoral leases (dating from 1852) for runs of up to 50 mi^2 (128 km^2, Jeans 1972); occupation rights went to the person that stocked the land first. Occupation applications have some of the earliest descriptions of these tracts of land. All original documents relating to leasehold land in New South Wales were destroyed in the Palace Garden fire of 1882. Examination of the Victorian records revealed few useful data.

Squatters were required to provide a 'description of the lands' in their lease application. Descriptions almost always only stated the location and boundaries of the run by reference to geographical features such as rivers, creeks, ridges and marked trees, so little useful information is in these descriptions.

Under the provisions of the various Lands Acts of the 1860s, colonists–'selectors'–were permitted to choose land from the unsold public domain. The area permitted to a selector was related to the amount of land he could clear and cultivate. Improvements, for which selectors lodged compensation claims, included erection of buildings and fences as well as cutting down trees, ringbarking and clearing the ground of fallen timber. Examination of these files revealed numerous claims for clearing logs or gathering and burning timber (Parkinson & Mac Nally 2000). Improvements are stated in terms of the amount of land treated, not in the amount of timber removed. Unfortunately, the rates of payment are not known, so that it is not possible to use this areal information to determine densities of fallen timber.

Surveys

Plans of all the Victorian parishes bordering the lowland reaches of the Murray, Ovens, Goulburn, Campaspe and Loddon Rivers were examined for descriptions of floodplain vegetation. The majority of plans gave no descriptions of the vegetation. Only a few plans gave any indication of the density or size of trees with descriptions such as 'heavily timbered with large swamp gums' or 'lightly timbered land with box, gum, pine and she-oak'. Estimates of tree density were noted on only two plans (Table 2)–eight large red gums per acre in the parish of Gooramadda, and ten large red gums per acre in the parish of Wodonga.

State colonial surveyors undertook measurements of the courses of all the major rivers during the mid-1800s. Most of the plans give some indication of the nature of the country along the rivers but only in general terms (e.g. 'swampy gum flats subject to inundation', 'poor box forest, thinly grassed').

Location	Large trees		Smaller trees	
(date)	Density	Description	Density	Description
Murray River, Gooramadda (1879)*	8/acre	'large red gum'		
Murray River, Wodonga (1881)*	10/acre	'large red gum'		
Goulburn River (1875)#	20/acre	'suitable for milling purposes'		
Barmah Forest (1870)#			80-100/acre	18-24 inches diameter
Millewa Forest (1895)#	2/acre 8/acre	'fit for saw-mill purposes' 'trees of full growth ...but hollow, spongy, and winding growth'	7/acre 2000/acre	16-20 inches diameter 'dense growth of young trees'
Gunbower Forest (1875)#	6/acre	'old trees...fit for sawing'	40-80/acre	20-60 ft in height, 6-18 inches diameter
Gunbower Forest (1878)#	6/acre	'trees fit for felling'		

Table 2. Estimates of tree densities within River Red Gum forests, derived from parish plans* and forestry reports#.

Pre-emptive rights were the homestead blocks purchased by squatters under regulations gazetted in 1848. Where runs included river frontage, the site chosen for the main homestead typically was adjacent to the river. Many of these allotments were located on floodplains. Pre-emptive right plans date from 1852-73 and show the boundaries of allotments and the location of landmarks such as buildings, fences and tracks. Some plans also include descriptions of the soil and vegetation, but again in general terms only (e.g. 'tolerable loamy soil, lightly timbered with flooded gums').

Pastoral allotments were properties purchased by selectors from the Crown. Vegetation descriptions were brief (e.g. 'good grass, red gum'). One plan from the vicinity of the Murray-Ovens junction was later amended, with references to both the nature of the forest and to the amount of fallen timber on the ground:

> 'Sparsely timbered, low lying land covered with debris from floods'
>
> 'Fairly well timbered with large Red Gum all over'
>
> 'Fairly well timbered hereabouts with big Red Gum and saplings'

Scientists and naturalists

Botanists and zoologists were commissioned by the government to undertake extensive collecting expeditions. The journals of these people provided valuable information on the nature of the landscape prior to European impact.

Botanist Daniel Bunce made one reference to fallen timber when describing the swollen Campaspe River after heavy rains:

> 'November 29 - This morning go to the river with the intention of crossing, but from the late rains we find that it is not only not fordable, but very rapid, bringing down large logs of wood.' (*The Argus* 14/3/1850, p. 2).

Von Mueller undertook a major scientific expedition along the floodplains of the Murray River–a 2500 km journey from November 1853 to April 1854. Mueller (1855) gave a detailed account of the various species of plants that he encountered but provided no descriptions the floodplain forests. The zoologist William Blandowski and the German botanist, Gerard Krefft, led an expedition to investigate the natural history of the region in the vicinity of the Murray-Darling junction. They did not provide any general descriptions of the countryside (Blandowski 1857).

Edward Curr was a squatter in the Barmah Forest region from 1841 to 1851. He described the

extent and impact of burning and a couple of references to the size of the River Red Gums (Curr 1965):

> '... it seems to me that its [Australia's] condition, when we took possession of it, was largely attributable to the customs of its aboriginal inhabitants ... there was another instrument in the hands of these savages which must be credited with results which it would be difficult to overestimate. I refer to the fire-stick; for the blackfellow was constantly setting fire to the grass and trees, both accidentally and systematically for hunting purposes...' (pp. 87-88)
>
> '... towering gum trees...' (Goulburn River near Seymour) (p. 36)
>
> '... the Murray with the grand trees on its banks...' (p. 168)

George Bennett made note of the large size of the River Red Gums that he encountered during his journey along the Murrumbidgee River during 1832:

> '... enormous trees of the *Eucalyptus* genus, called 'water gum' by the colonists; they attain from ninety to one hundred feet in height, with a diameter of from six to eight feet ...' (Bennett 1834:188)

Edmund Hobson also commented on the River Red Gums that he observed on the Murray River during his journey from Melbourne to Sydney in 1839:

> '... the trees on its banks are high luxuriant gums' (Hobson 1839 cited in Kenyon 1932:220)

Thus, despite making extensive journeys along the rivers of the Murray-Darling system and having a specific interest in the natural environment, the early scientists and naturalists left few descriptions of the general nature of the riverine forests and woodlands.

Forestry records

The earliest reports date from the 1870s and 1880s, a period during which timber cutting was particularly intensive and new regulations were being introduced. Examination of these reports revealed information about the extent of impact of forestry operations at the time (Table 3), as well as providing some data on the structure of the River Red Gum forests (Table 2).

Changes in the structure of the forests due to increased regeneration are also described in a couple of reports:

> 'Gunbower forest was originally rather thinly timbered, but the action of the floods has been to deposit seed in all the low ground ... From the appearance of the saplings, I think they must have been sown by the great flood of 1870, as they range from forty to sixty feet in height, and from nine to twelve inches in diameter at two feet from the ground.' (Gunbower forest, Votes and Proceedings of the Legislative Assembly of Victoria 1878)
>
> '... I have no hesitation in stating that where there was one young tree in 1875, when I took

Location	Extract
Gunbower Forest	'this forest contains very little virgin redgum' (Votes and Proceedings of the Legislative Assembly of Victoria 1878)
	'you will doubtless be surprised to see what a small portion of virgin forest remains'(Votes and Proceedings of the Legislative Assembly of Victoria 1878)
Barmah Forest	'it is almost thoroughly culled of its best timber' (Votes and Proceedings of the Legislative Assembly of Victoria 1875)
	'the timber on the river bank, and back for an average distance of two miles, has been either partly or entirely worked' (Votes and Proceedings of the Legislative Assembly of Victoria 1878)
	'the area bearing mature timber has been cut over several times during the past sixteen years' (Votes And Proceedings of the Legislative Assembly of Victoria 1899)
Goulburn River	'there is no virgin forest' (Votes and Proceedings of the Legislative Assembly of Victoria 1878)
Ovens River, Broken River and Murray River (Bundalong-Tocumwal)	'the red gum has been greatly worked out some years ago' (Votes and Proceedings of the Legislative Assembly of Victoria 1885)

Table 3. Extracts from forestry reports detailing the impact of timber cutting on river red gum forests.

> charge on these forest reserves, there are now twenty...' (Millewa forests, Votes and Proceedings of the Legislative Assembly of New South Wales 1895)
>
> '... thinning operations commenced in 1891 ... On the area first operated upon thousands of piles, fully 60 feet in length, from 18 to 20 inches in diameter, and as straight as arrows, could now be obtained. Had the forests been left in their unassisted state, where there are now from fifty to sixty such trees to the acre there would probably have not been more than five or six.' (Millewa forests, Votes and Proceedings of the Legislative Assembly of New South Wales 1895)

These reports clearly indicate that by the late nineteenth century, timber harvesting and silvicultural management had already had a major impact on the River Red Gum forests.

FACTORS AFFECTING FALLEN TIMBER PRODUCTION

Robinson (1997) found that old-growth River Red Gum woodland has a significantly higher load of fallen timber than younger stands, so tree size is an important determinant of fallen timber production. Historical changes in the age-structure of River Red Gum communities would, therefore, be expected to have associated changes in fallen timber abundance. Many photographs and reports from the 19th century show or refer to huge River Red Gums, much larger than most of those standing today (Bennett 1834: 188; Mueller 1879). It appears that the floodplain woodlands encountered in the early 19th century were of a much older age-structure than those of today.

Given that it is the large, veteran trees that are likely to produce most fallen timber, changing densities of these trees is critical. A limited number of density estimates were obtained from parish plans and forestry records (Table 2). The estimates for 'large' trees range from 6 to 20 trees per acre. The actual size of these trees is not defined, but they are generally described as being of a size fit for milling (> 2-3 feet in diameter).

European land-use may have contributed to this shift in the size-structure of River Red Gum stands, in particular: (1) changes in the burning regime and (2) intensive timber utilization.

Fire regime

Fires lit by lightning strikes or by aborigines were a common occurrence in the Australian landscape (e.g. Jacobs 1955; McArthur 1962; King 1963; Curr 1965; Jones 1969; Nicholson 1981; Dingle 1984; Fahey 1986; Boutland 1988; Pyne 1991; Flannery 1994; Dargavel 1995). River Red Gum saplings are extremely fire sensitive so that periodic burning impedes regeneration (Jacobs 1955; Dexter 1978; Gloury 1978; Robertson 1985). Large trees generally are able to withstand low-intensity ground fires (Robertson 1985). Therefore, the result of frequent, low intensity burning of the past was the maintenance of open stands of predominantly large, veteran trees living for 500-1000 yr (Jacobs 1955; Chesterfield 1986; Lyons 1988).

The large veteran trees of these woodlands most probably would have produced large volumes of fallen timber. However, the overall production of fallen timber by such woodlands may not necessarily have been high. Evidence suggests that the burning regime that existed at the time also maintained considerably lower tree densities than at present. The scant existing evidence suggests a similar pattern of change on the floodplains. Until late last century, River Red Gum vegetation appears to have been generally open.

Apparently many of today's River Red Gum forests are a legacy of extensive regeneration during the 1870s, due to a series of high floods and mild summers (Jacobs 1955; Dexter 1978). Successful establishment of River Red Gums was particularly high during this period (Jacobs 1955). The result was the development of relatively densely stocked stands of young trees.

Thus, although the areal density of trees in present-day River Red Gum communities may be significantly higher than in the past, this may be mainly due to establishment of large numbers of trees around 130 yr ago—trees that are still young for the River Red Gum. The change in the fire regime has probably had little effect on the density of older trees (although see quotes 32, 33 in Table 1). These trees have been subject to another pressure—timber harvesting.

Timber harvesting

The suitability of River Red Gum timber for many purposes was quickly realized and by the mid 1800s

was in great demand. Initially, the timber was exploited for heavy construction (Donovan 1997). Immense quantities of River Red Gum were consumed as firewood during the 19th century. The 1150 steam engines of Victoria's gold mines consumed > 10^6 tons of firewood p.a. (Blainey 1984). Vast quantities of timber were used for steam production for mills (Moulds 1991). Huge quantities of River Red Gums were cut for railway sleepers. Demand for red gum sleepers remained high for the next 100 yr.

Removal of timber from the Victorian side of the Murray River was so complete that, by the 1880s, River Red Gum timber from the New South Wales side of the river was required to satisfy Victorian demand (Donovan 1997; Votes and Proceedings of the Legislative Assembly of New South Wales 1895). Commissioned reports on state forests and timber reserves condemned the government's lack of control of state-forestry interests:

> 'In conclusion, we feel it our duty to point out that the forests of Barmah and Gunbower have not received the care and protection which should have been bestowed upon so valuable a State property. No private owner of extensive areas of redgum would for a moment deal with such an estate in the manner in which these important reserves have been managed and worked in the past.' (Votes and Proceedings of the Legislative Assembly of Victoria 1899)

The most significant effect of this long history of timber harvesting has been the removal or death of almost all the large trees. Most of the huge, old River Red Gums from the pre-European woodlands have long been removed. The majority of these trees would have been many centuries old. Thus, despite the regrowth that has occurred since this time, the River Red Gum forests would be of a much younger demography than those of the past.

Although forestry operations have contributed to a decline in the numbers of large, debris-producing trees, substantial amounts of logging residue also are produced (i.e. defective timber and the smaller branches of tree crowns). This is generally not, however, a source of long-term fallen timber. In the past, logging debris was piled up and burnt (Broughton1966), while now it is made available to firewood collectors (Donovan 1997; Read, Sturgess and Associates 1995).

FACTORS AFFECTING FALLEN TIMBER LOSS

Natural decomposition

Rates of decay of red gum wood are very low by world standards, with pieces of dead timber remaining intact for > 100 yr (Robinson 1997). It is unlikely that rates of decomposition of red gum debris have altered significantly over the last couple of centuries.

Removal by floodwaters

Two changes have occurred since the mid 1800s that may have influenced the extent of movement of floodplain debris, particularly the transfer of fallen timber from the floodplain into the main channel or drainage lines. The first is the changes in the nature of floods as a result of river regulation. Because winter/spring inflows into the river system are now held in storage for release to meet irrigation demands in summer and autumn, the large annual floods that occurred under the natural flow regime have declined in both magnitude and frequency (Close 1990). In the past, such floods may have resulted in the frequent redistribution of floodplain debris.

The second influence is the increased density of trees on many areas of floodplain due to the extensive regeneration that occurred late in the nineteenth century. This would inhibit the translocation of fallen timber, regardless of the magnitude of a flood. This factor alone is likely to have resulted in an overall decrease in the amount of fallen timber that would be transported off the floodplain.

Combustion

Frequent, low-intensity burning was prevalent on pre-European floodplains. Fires are now less frequent but would generally be of greater intensity. This change may have affected the rate at which fallen timber is lost from floodplains due to fires.

Fires within floodplain forests are relatively slow-moving due to the low-relief topography and relatively low fuel loads—coarse fuels are not important to the rate of spread of a fire (Tolhurst et al. 1992). Dry red gum wood will readily catch alight during forest fires, especially if partially decayed, and, once alight is long-burning until completely

consumed (L. Bren, *pers. comm.*). Therefore, considerable volumes of fallen timber are likely to be lost from floodplain ecosystems during fires, even those of low-intensity.

Firewood collection

River Red Gum is one of the most highly sought fuel-wood-tree species in temperate Australia (FTS & UT 1989). In Victoria, firewood represents the largest single use of products from public forests, at 1.2 to 2.5 $\times 10^6$ m^3 p.a. in 1995, compared with a total sawlog production of about 1.0 $\times 10^6$ m^3 p.a. and total pulpwood production of 0.9 $\times 10^6$ m^3 p.a. (Read Sturgess and Associates 1995). Although used primarily for household heating, the industry continues to undergo rapid growth (Donovan 1997). In the Millewa forests, use of residue timber from logging operations for firewood has increased from 5000 tonnes in 1985 to 35,000 tonnes in 1996 (Donovan 1997).

On public land, firewood collection (both commercial and domestic) is permitted only in designated areas of forest that are shifted periodically. Even so, large areas of land are sometimes almost completely denuded of fallen timber, particularly from areas close to towns (FTS & UT 1989).

CURRENT WOODLOADS AT BARMAH-MILLEWA

In 1997–1999, we undertook an extensive survey of fallen-timber loads across the entire southern Murray-Darling floodplain system (Mac Nally et al. 2000b). Part of this survey involved measurements of 60 0.5 ha plots randomly sited in the Barmah-Millewa forests. In each 200 m × 25 m transect, all pieces of fallen timber exceeding 10 cm diameter were measured.

From these data, and assuming a mass-density of 0.6 tonne m^{-3} (Robinson 1997), we estimated that the average extant load of fallen timber at Barmah was 24.36 tonne ha^{-1} and, at Millewa, 16.78 tonne ha^{-1}, both of which much exceeded the average load at Gunbower Island (11.78 tonne ha^{-1}) (Table 4). Our preceding historical analysis provided scant evidence to assess these figures against a possible pre-European figure. Robinson (1997) measured fallen timber loads in several old-growth, very isolated sites in Millewa, recording a figure of ca 125 tonne ha^{-1}. If this figure is more representative of pre-European loads, then all three floodplain forests, among the main extant representatives of the River Red Gum ecosystem, are likely to be very much impoverished. By using bootstrap resampling, we estimated that the total fallen timber load at Barmah was between 565,700 and 957,700 tonne, and between 432,300 and 710,300 tonne at Millewa (Table 4).

We have strong experimental evidence that loads of ≥ 40 tonne ha^{-1} are favoured by the near-threatened (Garnett & Crowley 2000) Brown Treecreeper *Climacteris picumnus* and the Yellow-footed Antechinus *Antechinus flavipes* (Mac Nally et al. 2002a; Mac Nally and Horrocks 2002). Therefore, even if the Robinson figure is unrepresentative, the current loads do appear to be much lower than desirable based on the needs of representative birds and mammals.

ACKNOWLEDGEMENTS

We thank the Murray Darling Basin Commission, the Australian Research Council, and the Hermon Slade Foundation for funding this work. The following persons provided important input: Peter Fairweather, Sam Lake, Malcolm Calder, Robert Price and Lance Lloyd. With also thank Geoff Goldrick, Lawrie Conole and Darren Ward for assistance with

Unit	Area	Transects	Transect mean	Unit totals[1] (summed over entire area)		
	ha	No	tonne ha^{-1}	Lower CL[2]	Mean	Upper CL[2]
Barmah	30,000	30	24.36	565,700	741,900	957,700
Millewa	33,600	30	16.78	432,300	562,600	710,300
Gunbower	21,000	30	15.99	272,700	335,900	392,200

[1] Data are expressed in tonne.
[2] CL, confidence limit (upper or lower 2.5%)

Table 4. Data on estimates of fallen timber in three Murray-Darling floodplain forests.

this work. The following persons were consulted during this work; and we thank them for their knowledgeable inputs: Rob Argent, Paul Barker, Steven Barlow, Leon Bren, Kevin Brewer, Sue Briggs, Michael Boggan, Helen Cohn, Mike Copland, Jim Crosthwaite, Brian Finlayson, Ben Gawne, Wayne Gilmore, Chris Gippel, David Harvey, Bob Inns, Ann Jensen, Kathryn Jerie, Christine Kenyon, Peter Knight, Keith Maplestone, Peter Murray, Joe Powell, Rob Price, Jane Roberts, Catherine Robinson, Ian Rutherfurd, Milton Smith, Michael Thompson, Kevin Tolhurst, Simon Treadwell, Arthur Wakeman, Keith Ward, and Karen White. This is publication number 80 from the *Australian Centre for Biodiversity: Analysis, Policy and Management* at Monash University.

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